

BP GROUP:
ACOUSTEK ASSESSMENT
A demonstration of a pipeline monitoring system,
Naval Petroleum Reserve No. 3, Teapot Dome Field, Wyoming

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ABSTRACT

The University of Manchester, BP, and the Rocky Mountain Oilfield Testing Center (RMOTC) jointly conducted a test using the Acoustek™ pipeline monitoring system. This patented new Acoustek technology has been developed primarily to offer early detection of hydrate blockages forming in wet gas lines. The gradual build-up of liquids in the line is also detectable. The system is based on establishing an acoustic signature of the healthy, unblocked line and then comparing this over time with updated acoustic signatures. Any change in the pipeline acoustic behavior can be identified and located. If no operational change can be identified to explain the change (e.g. valve position change) then the build-up of liquid or development of a blockage is implied.

Prior to the test at RMOTC, most experimental work has been carried out on laboratory test loops through the University of Manchester (plastic and steel) with air under static conditions. These tests suggest that Acoustek has the range and sensitivity to detect small changes in the acoustic signature of real-world piping systems.

This technology was tested at RMOTC on the high-pressure gas injection system. Baseline signatures were recorded as an Echometer gas gun injected acoustic pulses into the operating gas injection pipeline. Results from the test indicate that for no-flow conditions, the gas gun provides a suitable mechanism for applying the Acoustek™ technique. However, for application to pipelines containing flow, a more sophisticated acoustic pulse and receiver system is required.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
INTRODUCTION	2
BACKGROUND INFORMATION	4
RESULTS FROM FIRST TIE-IN POINT	5
<i>Equipment Set-up</i>	5
<i>Detection of Liquid Blockage at Atmospheric Pressure</i>	7
<i>Detection of Liquid Blockage at Elevated Pressure with Flow</i>	10
<i>Implosion Tests</i>	13
RESULTS FROM SECOND TIE-IN POINT	13
<i>Equipment Set-up</i>	13
<i>Analysis of Results from Second Tie-in Point</i>	15
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK.....	18
<i>Conclusions</i>	18
<i>Recommendations for Future Work</i>	19

LIST OF FIGURES

Figure 1. RMOTC gas injection system.	3
Figure 2. Map showing location of Teapot Dome on the Naval Petroleum Reserve No. 3 in East Central Wyoming, USA.	4
Figure 3. First tie-in point.	6
Figure 4. Gas gun connection.	6
Figure 5. Comparison of response with and without the valves located at the T-section being opened and closed.	8
Figure 6. Frequency content of signal.	9
Figure 7. Effect of closing isolation valve.	10
Figure 8. Background noise from compressor.	11
Figure 9. Effect of partially closing the isolation valve with flow.	13
Figure 10. Location of second tie-in point.	14
Figure 11. Gas gun attachment.	15
Figure 12. Isolation valve closed.	16
Figure 13. Close-up when isolation valve is closed.	16
Figure 14. Response with isolation valve opened.	17
Figure 15. Response with the valve to the well open.	18

EXECUTIVE SUMMARY

Acoustek™ is a pipeline monitoring system developed at the University of Manchester, with financial support from BP. It requires the injection of acoustic waves into the fluid contained in the pipe. One or more acoustic sensors are then used to record the passage of the waves along the pipe. Analysis of the time history of the acoustic reflections enables the changes in acoustic impedance associated with any leakage and blockage to be identified. The acoustic signal was originally introduced using a loudspeaker, however, more recently the Echometer gas gun has been used.

The objectives of this field trial were:

- 1) To test the ability of the Acoustek™ technique to survey a long, pressurized pipeline containing flowing natural gas.
- 2) To determine the feasibility of using the gas gun for injecting the acoustic wave into the gas.

In this trial, the gas gun was able to detect what appeared to be a complete blockage of the pipeline caused by a deposit of water. This blockage could be detected readily without flow but was not clear under flow conditions. The introduction of flow was found to increase the level of background noise, which desensitized the technique and it is also believed that with flow, the gas will have bubbled through the water blockage, creating a much less defined interface and reducing the acoustic reflection.

Using a second tie-in point on the gas injection system, more blockages were detected. One of these blockages appeared to be close to the gas gun. However, a second blockage appeared to be present at a distance of approximately 2,200 feet away from the gas gun.

The results from the trial suggest that for no-flow conditions the Echometer gas gun provides a suitable mechanism for applying the Acoustek™ technique. However, for application to pipelines containing flow, which would be required for a continuous system, a new acoustic injection system is required. The results from this, and other tests, suggest that this system should include a source being a sequence of strong pulses, such as a pseudo-random binary sequence or chirp signal with a highly sensitive pressure transducer as a receiver.

INTRODUCTION

Previous trials with the Acoustek™ technology, such as the tests conducted on a UK North Sea platform and at the Petrofac Training Centre in Montrose, illustrated that under static pipeline conditions, Acoustek™, using the Echometer gas gun to inject the acoustic signal could be used to detect full and partial blockages in pipelines with lengths exceeding 10 km. To evaluate the capability of the same technique to detect and locate blockages in long lengths of pressurized pipeline, containing flowing gas, the technique was applied to the gas injection system, located at the Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming, USA. This system contained approximately 4 miles of steel pipeline, which varied in outside diameter from 2" to 3". The maximum flowrate in the pipeline was approximately 900,000 scfd and the maximum pressure was approximately 350 psig.

Figure 1 shows a schematic of the gas-injection system. For the first tests, the gas gun was connected approximately 50 feet downstream of the gas plant and for the later tests, it was connected at the well labeled 401-A-10.

During the trials, the data collection phase of which lasted a total of three days, a series of tests were conducted. These tests were performed with and without flow in the pipeline, and at atmospheric and pressurized conditions. This report describes the results obtained when the gas gun was located close to the gas plant and presents the results from the second tie-in location. Conclusions from this trial and recommendations for future work are also detailed.

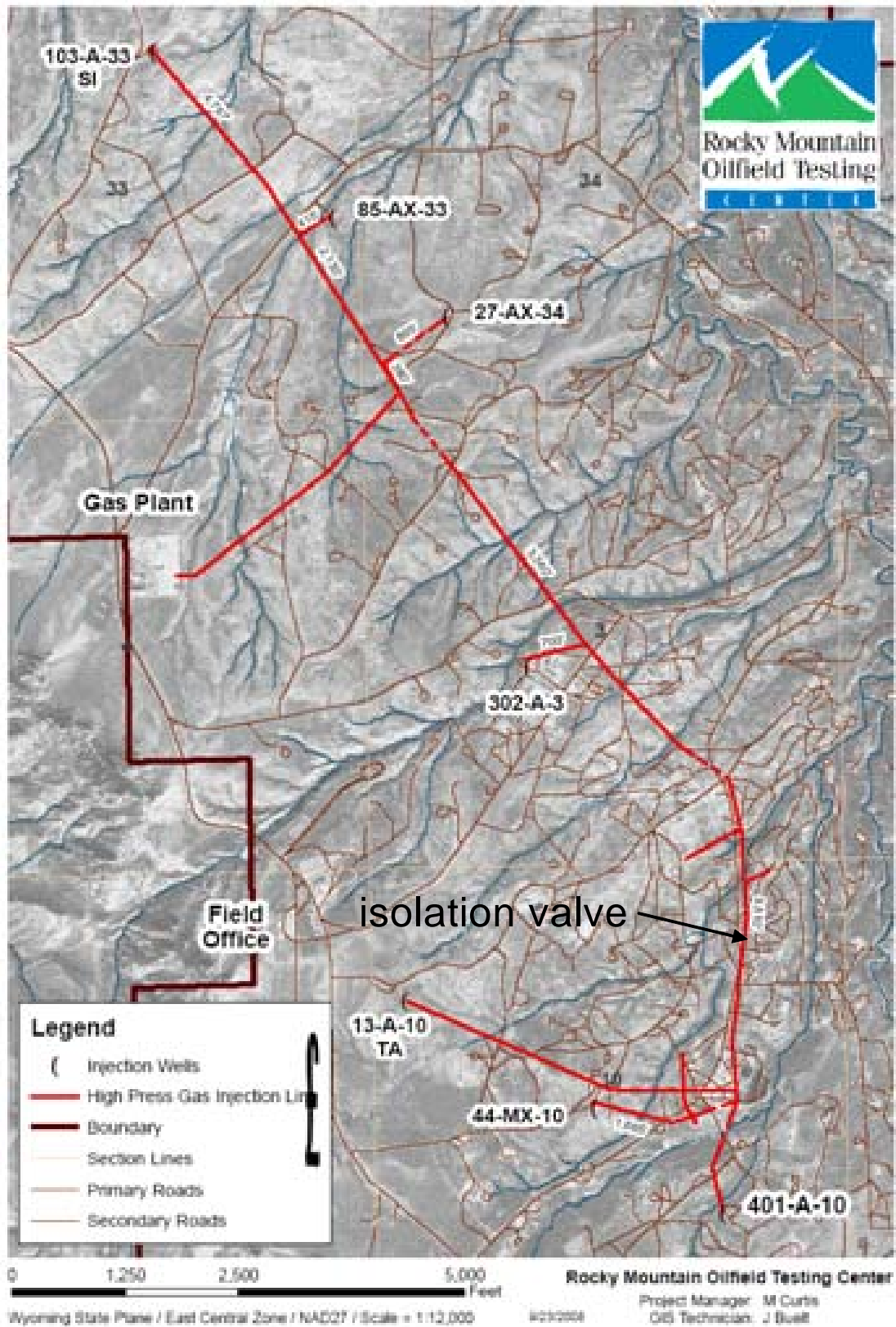


Figure 1. RMOTC gas injection system.

BACKGROUND INFORMATION

This test was performed at the Rocky Mountain Oilfield Testing Center (RMOTC) field site within the Naval Petroleum Reserve No. 3 (NPR-3), located approximately 35 miles to the north of Casper, Wyoming (Figure 2). NPR-3 is situated on the Teapot Dome Anticline in the Powder River Basin, Wyoming. Teapot Dome is the southern extension of the much larger Salt Creek Anticline. The Teapot Dome oilfield has a rich history dating back to the early twentieth century. During that time, over 1,300 wells have been drilled into the structure which consists of a doubly plunging anticline cored by a basement high-angle reverse fault. Today at NPR-3, there are approximately 300 active wells producing oil and gas from several different geologic formations.

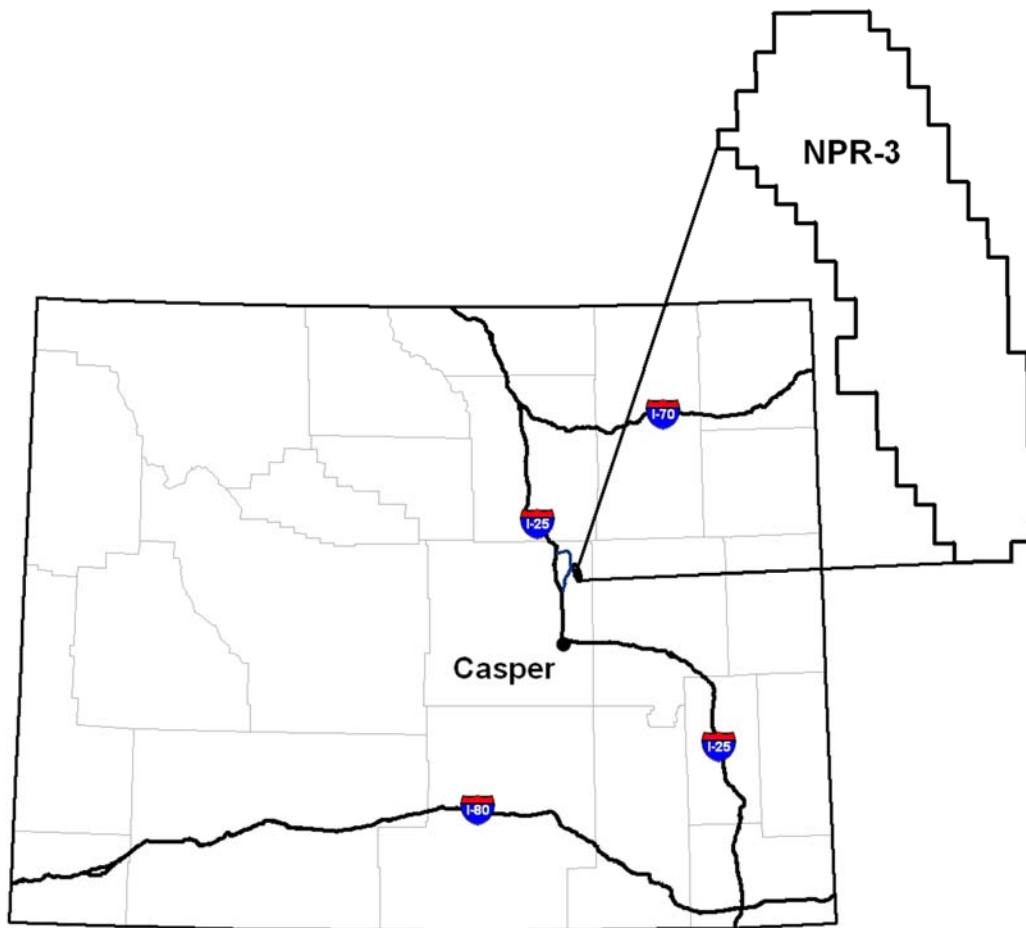


Figure 2. Map showing location of Teapot Dome on the Naval Petroleum Reserve No. 3 in East Central Wyoming, USA.

RESULTS FROM FIRST TIE-IN POINT

Equipment Set-up

During these tests, the gas gun was located approximately 50 feet downstream of the gas plant. Figures 3 and 4 show two photos which illustrate how the gun was connected to the pipeline. Figure 3 shows the location of the gas gun relative to an isolation valve, which was located approximately 283 feet from the gas gun. The pipeline travelled along the surface for approximately 271 feet after the gas gun. There was then a drop of approximately 9 feet, a further 2 feet of straight pipe and at this point an isolation valve was located.

The flow of gas from the gas plant came along pipeline on the right in Figure 3 and the gas gun was able to inject directly into this line. Two ball valves were located between the gas gun and the pipeline and these valves were fully opened during all the tests.

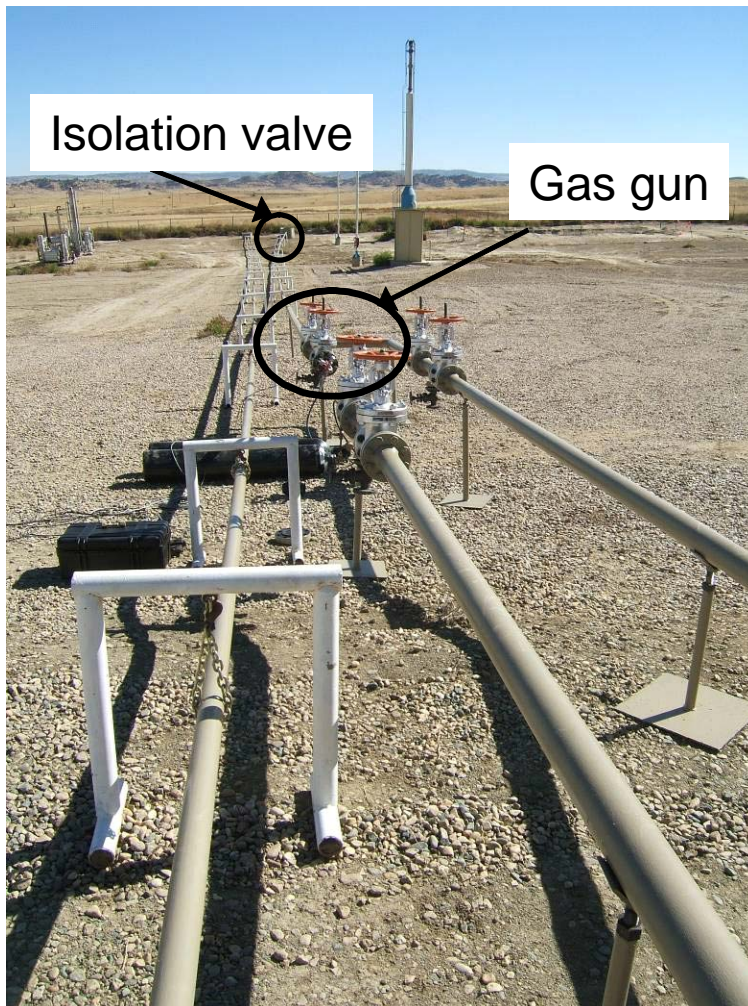


Figure 3. First tie-in point.



Figure 4. Gas gun connection.

With the gas gun connected to the first tie-in point, the following tests were conducted:

Test 1: Atmospheric pressure in pipeline, 56F, gas gun charged to 1,000 psig, compressor off. All valves to the wells open.

Test 2: Atmospheric pressure in pipeline, 60F, valves located at the T-section (approximately 3,600 from the gas gun) were both closed. Gas gun charged to 1,000 psig, compressor off.

Test 3: Atmospheric pressure in pipeline, 65F, isolation valve located 283 feet from the gas gun was closed. Gas gun charged to 1,000 psig, compressor off.

Test 4: Compressor on, pressure in pipeline increased to 150 psig. 75F. Isolation valve and all valves to the wells open. Gas gun charged to 2,300 psig. Flow of 900,000 scfd.

Test 5: Compressor on, pressure in pipeline increased to 140 psig. 69F. Isolation valve was approximately 75% closed. Gas gun was charged to 2,300 psig. Flow of 900,000 scfd.

Test 6: Pressure was increased in the pipe to 350 psig and then to 500 psig when an attempt was made to move the blockage detected in the previous tests by rapidly depressuring the line. Pressure in the pipeline was returned to 180 psig, 60F. Gas gun charged to 2,300 psig.

Test 7: Compressor on, pressure in pipeline increased to 150 psig. 75F. Isolation valve and all valves to the wells open. Gas gun operated in implosion mode. Flow of 900,000 scfd.

Note that for each test, unless otherwise stated, the average of ten repeats tests was made.

Detection of Liquid Blockage at Atmospheric Pressure

Figure 5 compares the reflected signal that was recorded during tests 1 and 2. Assuming a speed of sound of approximately 1,292 feet/sec (using the AGA 10 standards) and a distance of approximately 3,650 feet between the gas gun and the T-section where the valves are located, then it would be expected that there would be a significant difference in the reflected signals approximately 5.7 seconds after the gas gun was discharged.

Figure 5 shows that there is very little difference between the two reflections, suggesting that the acoustic signal does not reach the T-section.

The cyclical effect in the response suggests that there is an obstruction relatively close to the gas gun which the acoustic signal is reflecting off. The distance to this obstruction is approximately 299 feet. Later tests indicated that this obstruction was located at the same point as the isolation valve, i.e. 283 feet from the gas gun. This would provide a calibrated speed of sound of 1,208 feet/sec. The reason for the discrepancy with the AGA 10 estimated value for the speed of sound is that the composition of the gas was not known exactly.

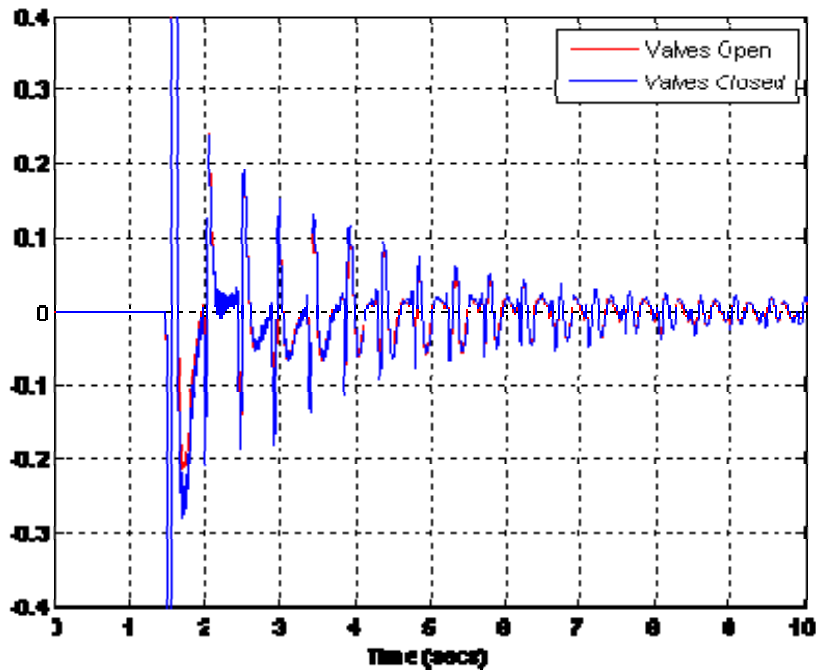


Figure 5. Comparison of response with and without the valves located at the T-section being opened and closed.

Figure 6 shows the frequency content of the acoustic signal introduced into the pipeline. This figure shows that the major component of the injected signal has a frequency content of approximately 5-10 Hz. A cyclic pattern is seen in this figure as the signal reflects between the obstruction and gas gun.

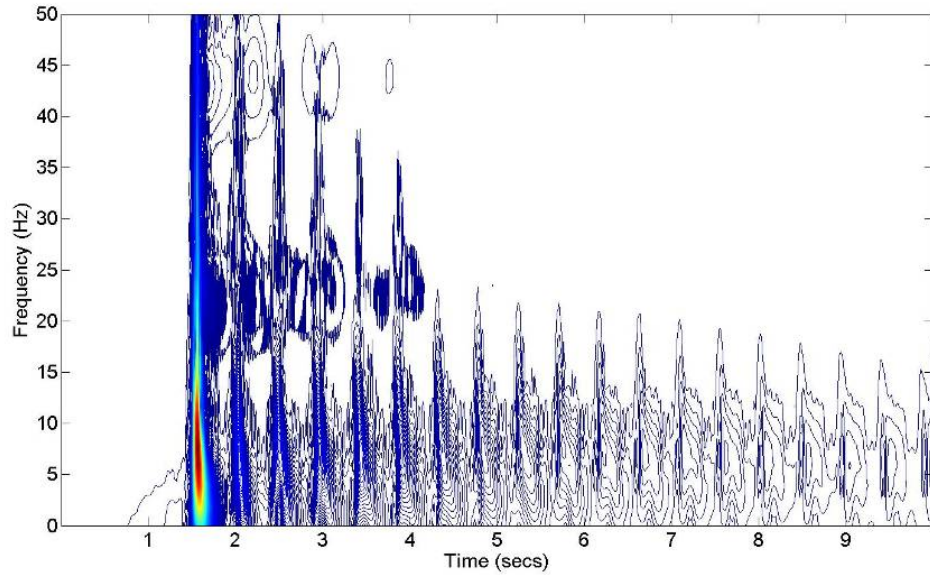


Figure 6. Frequency content of signal.

Figure 7 compares the signal that is reflected when the isolation valve is opened and then closed. This figure confirms that there is an obstruction located close to the isolation valve. Interestingly, the reflection from the valve appears to be more rounded than that produced by the other obstruction. The reason for this will be investigated further in the laboratory.

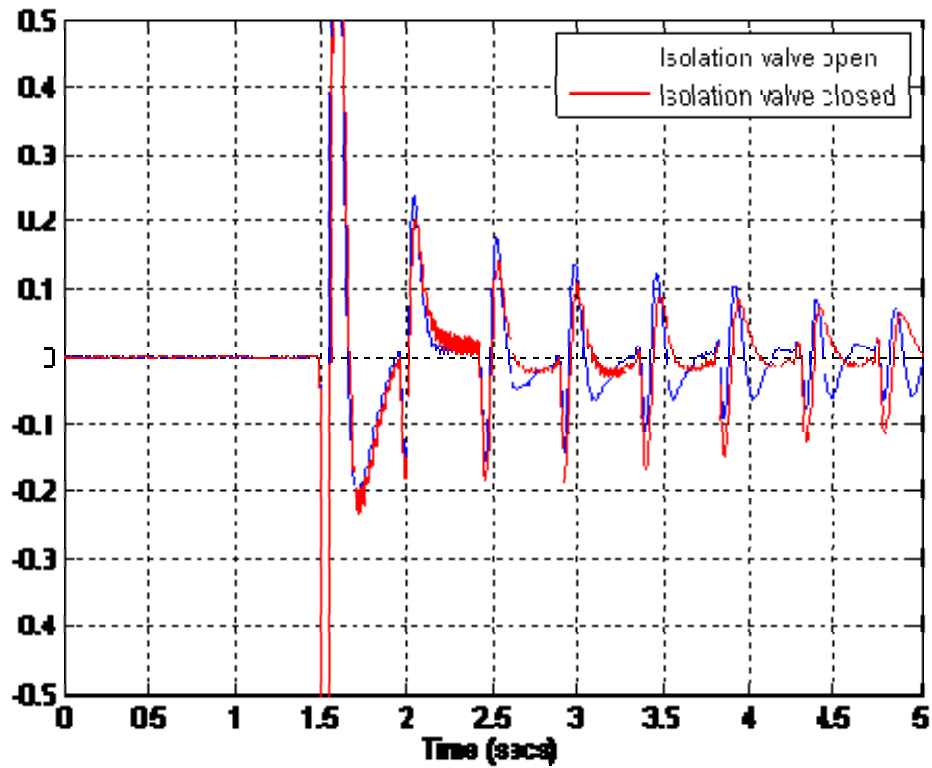


Figure 7. Effect of closing isolation valve.

Detection of Liquid Blockage at Elevated Pressure with Flow

Figure 8 shows the effect that the compressor had on the background noise recorded by the microphone. In this figure, the gas gun was discharged after approximately 1.5 seconds while the compressor was switched off. The compressor was then switched on after approximately 25 seconds. As the compressor was switched on the background noise increased sharply.

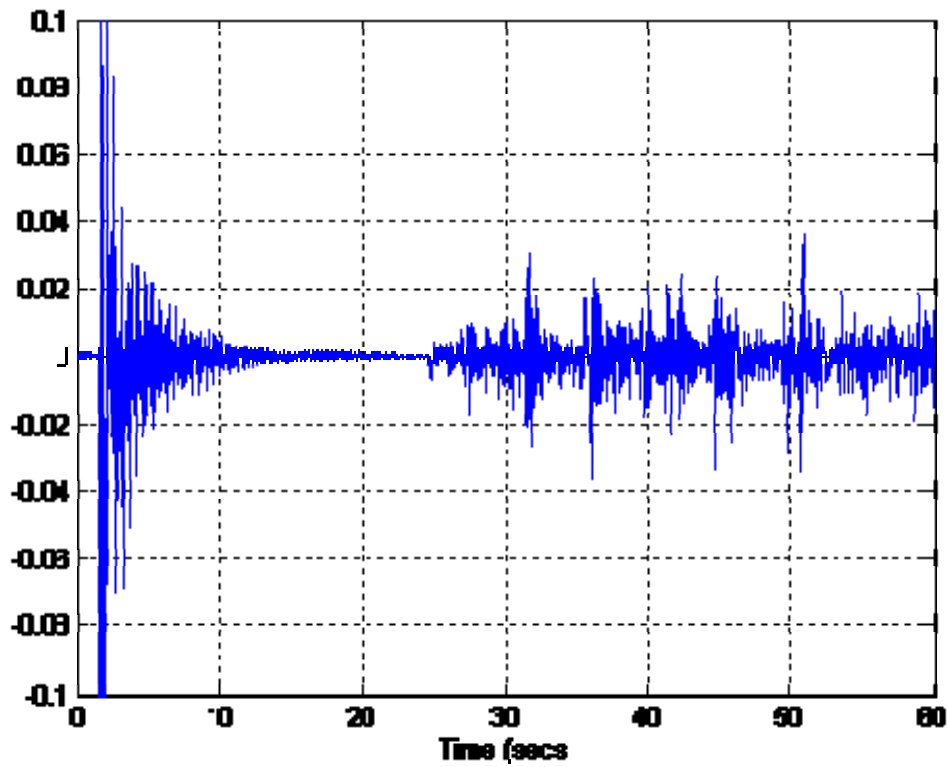


Figure 8. Background noise from compressor.

Figure 9 compares the signal measured during tests 4 and 5. During test 5, the isolation valve was closed until the point where the valve just began to restrict flow as indicated by an increase in back pressure at the exit of the gas plant. At any opening greater than this, the pressure drop across the valve would have been negligible.

Figure 9 shows that there is a clear difference between the reflections when the valve was partially closed. The major difference between the signals occurs approximately 0.463 seconds after the gas gun was discharged, which positions the obstruction at the location of the valve. It is interesting to note that unlike the static tests which showed a very clear reflection after approximately 0.5 seconds, there is no reflection when there is flow in the pipe. The reason for this is believed to be because the gas is able to *bubble* through the blockage which means that there is no clear interface between the gas in the pipeline and the liquid blockage. Hence there is no significant reflection produced.

The reason for the high frequency variation when the valve was open (the red trend in Figure 9) is because the dehydration unit was bypassed during these tests. The dehydration unit acted as a filter and dampened much of the noise from the compressor.

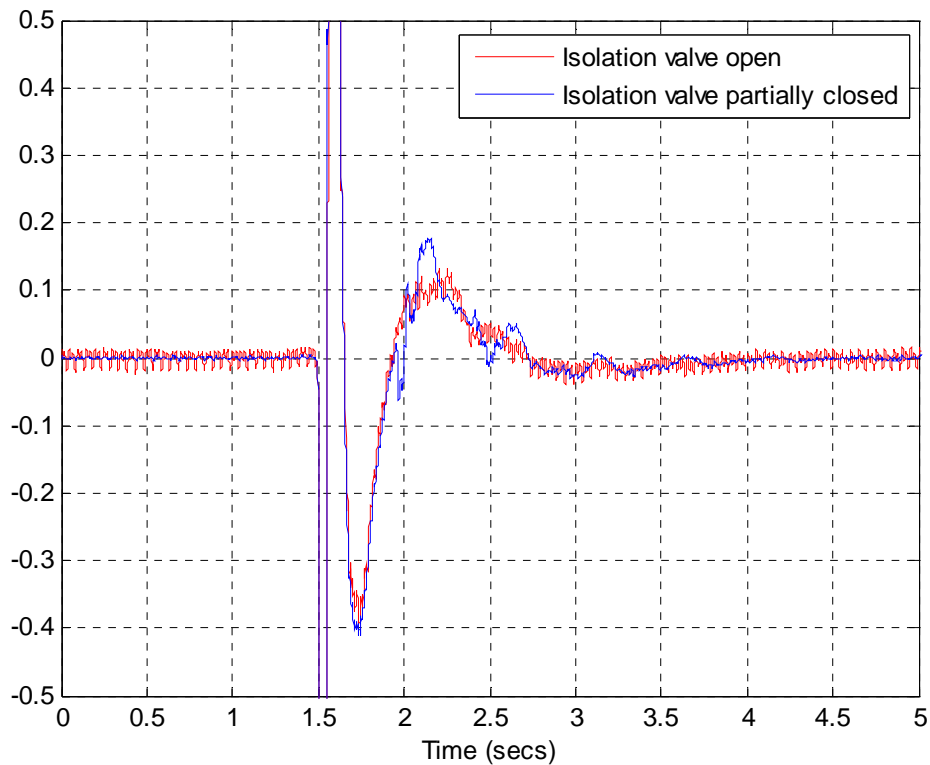


Figure 9. Effect of partially closing the isolation valve with flow.

Attempts were made to blow the liquid blockage down the pipe, but unfortunately test 6 showed no change in the location of the obstruction.

Implosion Tests

An implosion test (test 7) was conducted under flow conditions, but as with the explosion tests, there was no significant reflection observed where the obstruction was detected under static conditions.

RESULTS FROM SECOND TIE-IN POINT

Equipment Set-up

The second tie-in point was located at the well marked 401-A-10 on Figure 1. Figures 10 and 11 show the location of the gas gun at this tie-in point.

With the gas gun located at this tie-in point, the following tests were conducted:

Test 1: The isolation valve, labeled in Figure 1, and the well valve were both closed. Pipe was at atmospheric pressure, 88F. Gas gun charged to 2,300 psig.

Test 2: Well valve was closed but the isolation valve was opened. Pipe was at 93 psig, 92F. Gas gun charged to 2,300 psig.

Test 3: Well valve and isolation valve were both opened. Pipe was at 93 psig, 96F. Gas gun charged to 2,300 psig.

Test 4: Well valve and isolation valve were both opened. Valve at T-section, close to the gas plant was closed. Pipe was at 93 psig, 96F. Gas gun charged to 2,300 psig.

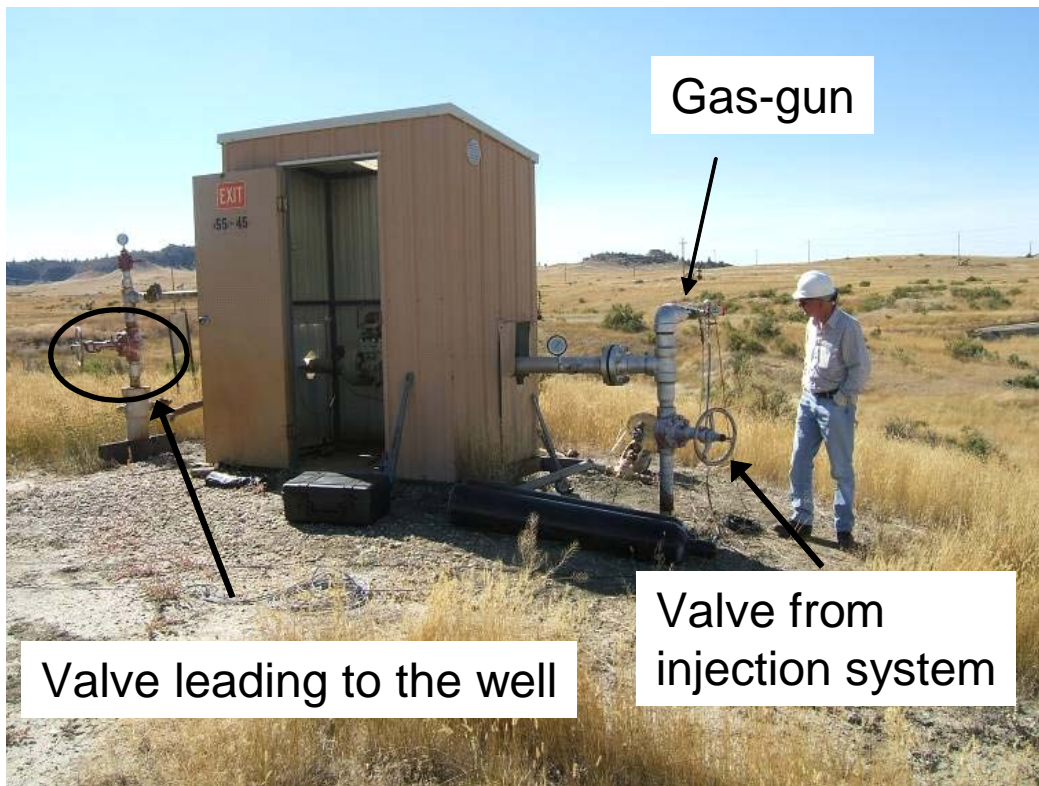


Figure 10. Location of second tie-in point.



Figure 11. Gas gun attachment.

Analysis of Results from Second Tie-in Point

Figure 12 shows the acoustic response measured for test 1. The response shows that there is a cyclic response with a period of approximately 0.426 seconds. The first reflection is observed approximately 0.385 seconds after the gas gun is discharged, which assuming that the speed of sound is approximately 1,208 feet/sec then this would suggest that there is a blockage 230 feet from the gas gun. The difference between 0.426 and 0.385 seconds represents twice the distance between the gas gun and the valve leading to the well, which is approximately 25 feet.

Figure 13 shows a close-up of the reflected signal shown in Figure 12. This indicates that in addition to the blockage after 230 feet, there is an obstruction at a distance of approximately 2,450 feet from the gas gun (the cyclic nature of the trace is seen to change in appearance after approximately 5.5 seconds in Figure 13). This would be at a location upstream of the T-sections to the wells marked 13-A-10 and 44-MX-10. This suggests that the obstruction located 225 feet from the gas gun is a partial blockage and that some of the acoustic signal passes through it.

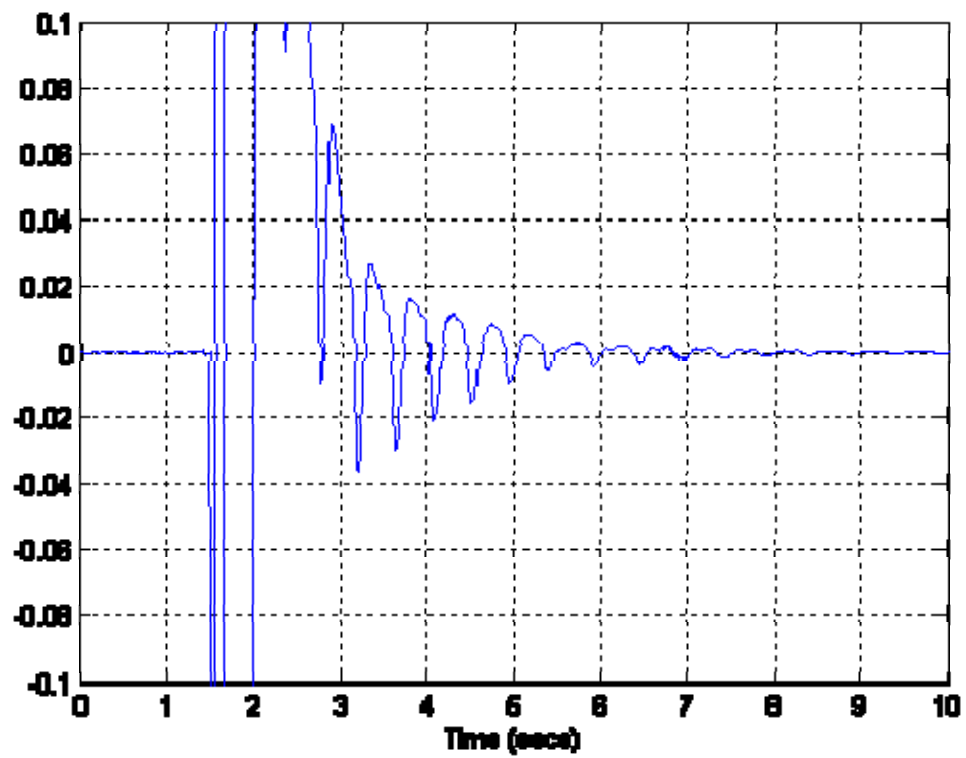


Figure 12. Isolation valve closed.

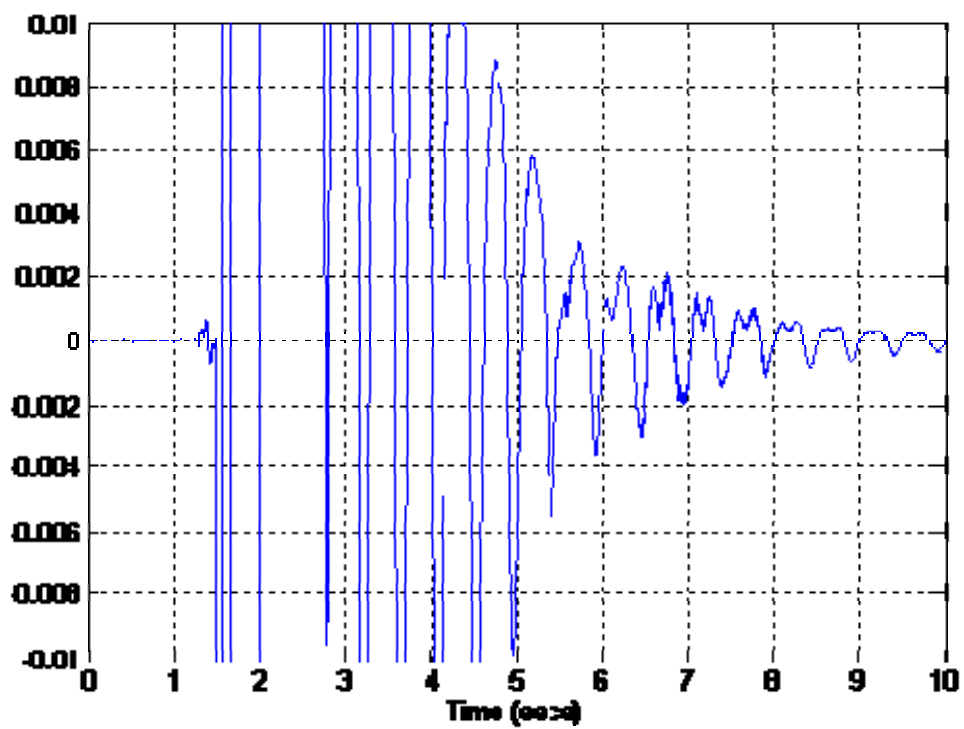


Figure 13. Close-up when isolation valve is closed.

Figure 14 shows the response that was recorded when the isolation valve was opened. The response for this test was much more uniform, with little change in the shape of the oscillations. The cycle time during this test was approximately 0.37 seconds, which is slightly less than the previous test (0.43 seconds). This result is surprising as the speed of sound for this test should be slightly less than for test 1 as the pressure has increased and suggests that the blockage may have moved towards the gas gun by as much as 30 feet when pressure was applied to the line.

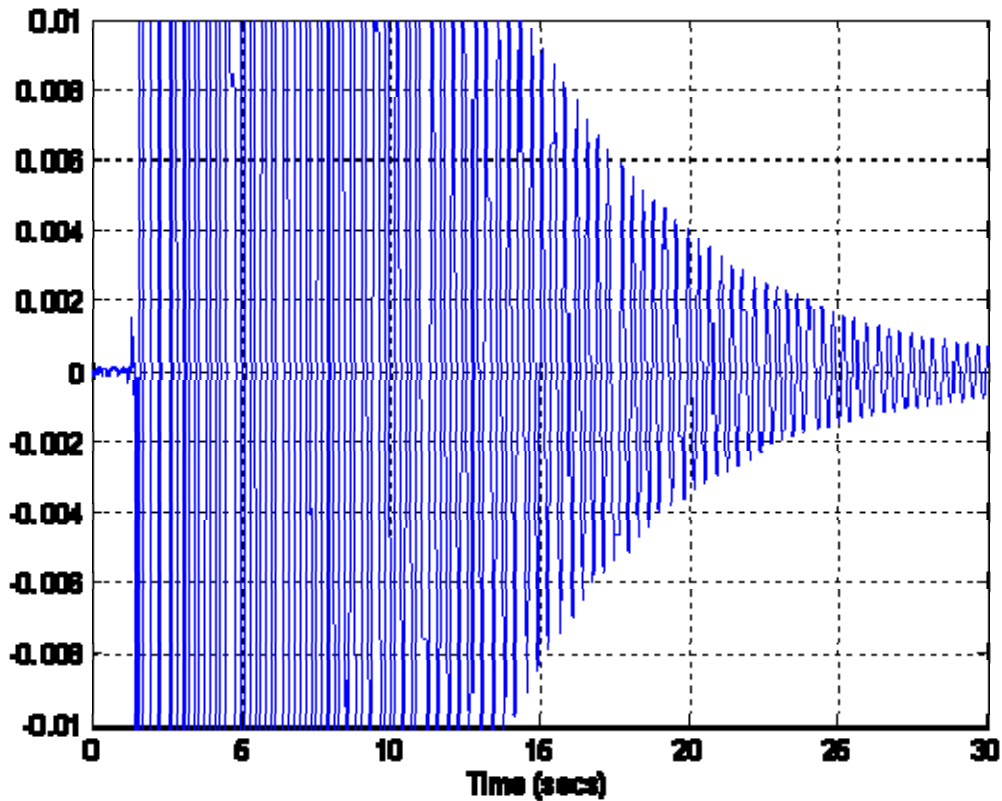


Figure 14. Response with isolation valve opened.

Figure 15 shows the response when the valve leading to the well was opened. This figure shows that the oscillatory nature of the response has now stopped and that there is a clear reflection from the base of the well approximately 4.5 seconds after the gun was discharged. This would indicate that the depth of the well was approximately 2,800 feet.

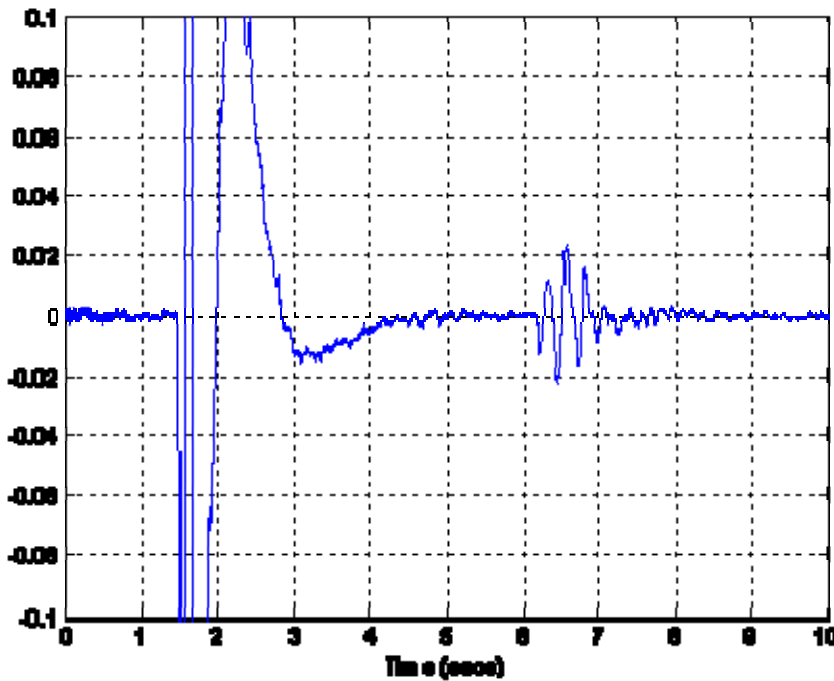


Figure 15. Response with the valve to the well open.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Conclusions

The Acoustek™ technique was able to survey the pipeline using the Echometer gas gun as the method for introducing the acoustic pulse. The analysis revealed at least two blockages in the pipeline, but unfortunately these blockages were located close to the two points that the gas gun was attached to the pipeline, which meant that the acoustic signals could not penetrate far along the pipeline.

The results demonstrated that the background noise presented a problem for the technique even with the relatively low flow rates encountered. The background noise, the origin of which is believed to be from the turbulent flow, desensitizes the technique significantly.

Recommendations for Future Work

For static pipeline or in pipelines where the flow is not turbulent, the gas gun would appear to be a suitable piece of equipment for introducing the acoustic signal into the pipeline. However, for monitoring pipelines where there may be flow or there may be significant levels of background noise, the gas gun is probably inappropriate. In such situations the size of the acoustic pulse should be larger, so that the size of reflections will exceed the background noise. Furthermore, the technique would benefit by introducing a more complex acoustic signal into the pipeline, such as a chirp signal or pseudo-random binary sequence. The advantage of this is that a more complex signal would be easier to distinguish from the background noise. The next phase of the research should therefore focus on the development of updated or customized equipment for applying the Acoustek™ technique.